TETA TO-0014
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TEST EFFECTIVENESS TREND OBSERVATION

Problem/Failure History versus Origin of Flight Hardware

CONCLUSION:

A conservative environmental test program, such as that defined in JPL Document D-1489 for Class A Flight Programs, has resulted in highly reliable spacecraft hardware. Less conservative programs considered to-date have experienced a higher incidence of flight problems and operational difficulties.

DISCUSSION:

The purpose of this study is to compare (1) test and flight histories of hardware on flight pro ects built to JPL product assurance standards for Class A hardware, as defined in the document: Flight Equipment Classifications and Product Assurance Requirements, JPL D-1489, Rev. B, January, 1990, with (2) hardware built to less rigorous standards.

The comparison is made using four pro ects with both test and flight history, Viking Orbiter, Voyager, Magellan and Galileo, and two with only a test history, Mars Observer and TOPEX/Poseidon. Viking, Voyager, and Galileo were built to JPL Class A standards; Magellan, TOPEX/Poseidon, and Mars Observer had both hardware built to Class A standards and hardware built to less conservative standards.

Magellan is currently the only program with both test and flight history and with a mix of some hardware built to Class A standards and some to less conservative standards. Magellan is considered a Class A pro ect in the system contractor mode. The system contractor was responsible for the procurement and testing of the spacecraft bus hardware and for the integration of the government furnished equipment (GFE supplied by JPL) and the synthetic-aperture radar (SAR) payload hardware. JPL was generally responsible for the environmental testing of GFE. The SAR contractor was responsible for testing that hardware. The procurement of the SAR proceeded the same as any other flight subsystem procured for a JPL S/C, such as a radio. However, the complexity of the SAR, if measured by the number of electronic parts, is equivalent to the rest of S/C. Therefore, the SAR procurement was much like a subsystem procurement managed by JPL, but the SAR complexity and significance was much greater. If the SAR had failed the mission was over. The number of parts for the entire S/C lies in between the Viking Orbiter (~30000) and Voyager and Galileo (60,722 and 68,700 respectively).

The assembly-level environmental test program conducted by the Magellan system contractor differed from a typical JPL program in the following ways. There was no sine test and the thermal-vacuum qualification/protoflight upper-level test temperatures were lower. On the other hand, the SAR contractor conducted an environmental test program generally similar to that applied on a typical JPL program.

Jet
Propulsion
Laboratory

The ground-test problem/failure reports (PFRs) for all six flight programs, as well as inflight anomalies for all programs (Mars Observer and TOPEX/Poseidon still are very early in their flight history) were reviewed. In order to provide a similar comparison of all programs, both ambient and environmental-test PFRs were considered because the data source for Magellan did not provide a separation. The Magellan PFRs were designated according to whether they occurred in hardware under the cognizance of the system contractor, or JPL or the SAR contractor. The JPL and SAR contractor PFRs are combined in Table 1 and have a complexity comparable to the S/C as noted above.

Table 1 provides a comparison of the programs with both test and significant flight PFR histories. The second column provides the number of ma or subsystems in the spacecraft bus hardware and the facility instruments. These are the subsystems on which test and flight PFRs were counted. The third column provides the number of test-hardware sets, and the fourth the number of flight S/C. The fifth column provides the number of test PFRs normalized by the total number of subsystems. The sixth column is the annual rate of flight PFRs per subsystem over the first three years of the flight mission. The seventh column provides a measure of the effectiveness of the product assurance requirements in reducing flight problem/failures in the form of the ratio of flight PFRs to test-induced PFRs.

Table 1. Measure of Effectiveness of Product Assurance Requirements in Reducing Flight PFRs

PROGRAM	NO OF SS	NO. OF HDWR SETS	NO. OF FLT S/C	NO. OF TEST PFRS/TOTAL NO. OF SS	NO. OF FLT PFRS per S/S / NO OF S/C-YRS, FOR 1ST 3 YRS OF FLT	AVE RATE FLT PFRS/ NO. OF PRELAUNCH PFRS (COL.6/ COL.5) X 10^{-3}
VIKING ORBITER	14	3	2	49	0.083	1.7
VOYAGER	15	3	2	46	0.24***	5.2***
GALILEO	15	1	1	180	0.42	2.3
MAGELLAN CLASS A D1489 HDWR*	3	1	1	156	0.78	5.0
MAGELLAN < D1489**	5	1	1	63	1.27	20.0

* since this includes the SAR which is as complex as the rest of MGN Flt hardware the results obtained are upper limit conservative values.

** e.g. modified thermal & vibration test

*** Values for Voyager for the entire time since launch (in its 15th yr of operation) are significantly different; column 6 value is, =.06; the corresponding value for column 7 is 1.3.

The ratio of the rate of flight to prelaunch PFRs is taken as a measure of the effectiveness of the test program where effectiveness is defined as the ability to uncover problems prior to launch. Table 1 shows values for this ratio vary at most by a factor of three from Viking Orbiter through Magellan hardware built and tested to Class A D-1489 standards. A large incremental increase occurs in going from Magellan hardware built to the D-1489 standards and that not so built; the value of the ratio being at least a factor of four higher than any of the other values.

This result tends to expand and confirm the conclusion reached in TETA TO-0002 which compared test and flight PFR histories for selected assemblies procured for both Magellan and Galileo. As stated above, these results emphasize the importance of a rigorous environmental test program in producing highly reliable spacecraft hardware.

The recently launched Topex and Mars Observer spacecraft will provide further opportunity to explore the issue of the PFR history of flight hardware. A study of these two pro ects, will further augment the test history on hardware not built to the conservative D-1489 standards.

The PFRs were also sorted according to the subsystem to which they were assigned. The subsystems, in turn, were classified according to their origin, whether they had heritage to previous contractor or JPL programs or were new hardware being developed by either.

Tables 2 and 3 summarize the distribution of PFRs for Mars Observer, which is a program managed by a system contractor. The PFR distribution is based on the cognizance of the hardware, either JPL or the system contractor. JPL had cognizance over the payload and some additional subsystems.

Table 2. Distribution of PFRs on Mars Observer According to Cognizance of Subsystems in Which PFRs Occurred+

Cognizance of Hardware	No. of Subsys. or Inst.	No. of PFRs	Ave
JPL	10	63	6.3
System contractor	8	102	12.8

+ Thirty five PFRs were assigned to system-level or S/C testing.

Table 3. PFRs on Mars Observer Resulting From Inherited or New Assemblies Developed by the System Contractor

Origin	No. of Subsystems	No. of PFRs	Ave
New	5	60	12
Inherited	4	38	9.5
Undetermined	1	4	4

The environmental-test program conducted by the system contractor on Mars Observer (MO) was less rigorous than normally conducted on JPL Class A programs; no assembly-level sine vibration test was performed and in many cases temperature/atmosphere tests were used in place of thermal/vacuum testing. As shown in the tables above, the comparison between non-JPL hardware and system-contractor generated hardware, involves both new hardware and hardware with heritage to both NASA and Air Force programs.

Although the MO prelaunch test program produced PFRs at a rate enveloped by results obtained in the Viking, Voyager, and Galileo programs, Table 2 indicates that there were twice the number of PFRs in system-contractor-cognizant hardware than in JPL-cognizant hardware, when the number of subsystems involved is taken into account. However, the difference due to testing and the impact of design and control differences can not be determined until flight results are analyzed.

Topex/Poseidon, which is a Class B pro ect (JPL D-1489) managed in the system-contractor mode, had 605 assembly-level PFRs during testing. This rate of PFR generation was about 2-2.5 times that which occurred on the Viking, Voyager and Galileo Programs. The first two programs cited had significantly more hardware sets in testing (see table 1). The high PFR rate is a good indication issues were being reported but also an indication that there were more issues. The significance of this is still TBD as in the case with Mars Observer.

Table 3 indicates that the ratio of PFRs in new vs inherited hardware developed by the system contractor is about 1.3, (taking into account the number of subsystems). It would be expected this ratio would have been larger and that newly developed hardware would experience more PFRs than hardware whose heritage involved previously flown hardware. From the data provided one could infer an excellent design and analysis program on the new hardware, however this will need to be validated by the flight data.

The assembly-level environmental test program for Topex/Poseidon involves less testing compared to the nominal D-1489 test program. There was no sine vibration or pyro shock test; a temperature/atmosphere instead of a thermal/vacuum test with lower temperatures and shortened durations was conducted on many assemblies. The lower temperatures and durations at the assembly level were to be compensated for by the system level test. Programmatic issues caused the planned duration of the system-level test to be shortened to the point where the expected compensation did not occur. Also, there was no EMC/ESD testing on most heritage hardware until the system level, the risk was considered low. Finally, inherited designs were not changed simply to meet D-1489 design and test requirements.

This Trend Observation will be revised to incorporate Mars Observer and TOPEX/Poseidon flight history when significant time has elapsed. A key area of interest will be whether the less conservative test program was or wasn't a factor on flight performance.